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Technical Report 140

Hawaiian hoary bat inventory in national parks on the islands of Hawai`i, Maui and Moloka`i

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ABSTRACT

Because bats are often the only native terrestrial mammals on geographically isolated island systems, they are critical to the biodiversity of mammalian fauna. The endemic Hawaiian hoary bat (*Lasiurus cinereus semotus*) is the only extant species of bat found in the Hawaiian Islands. The objectives of the Hawaiian hoary bat inventory were to determine presence/no detection of bats in national parks and adjacent areas on the islands of Hawai`i, Maui, and Moloka`i, assess distribution of bats in these national parks, and make general associations between bats and selected habitats and elevations. We used acoustic detection systems, along with visual observations, to accomplish these objectives. Through repeat surveys of points established in Hawai`i Volcanoes National Park, we found that bats occupied 33% of study sites from April to July 2005. In addition, we found that bats occupied 44% of sites established on the west side of Hawai`i Island in Kaloko-Honokōhau National Historical Park, Pu`ukoholā Heiau National Historic Site, and Pu`uhonua o Hōnaunau National Historical Park. Since we were only able to do a brief survey of Haleakalā National Park and Kalaupapa National Historical Park, we did not calculate site occupancy proportions for these parks. Results of our survey show that from April to June, Hawaiian hoary bats are most active 40-60 minutes after sunset, but they begin to emerge earlier in July. Furthermore, they appear to be opportunistic and forage in a variety of habitats, including native and non-native forests and shrublands, along roads and trails, and over areas of fresh/brackish water and open ocean.

INTRODUCTION

As the only extant terrestrial mammal native to Hawai`i, the Hawaiian hoary bat (*Lasiurus cinereus semotus*) is important to the biodiversity of vertebrate fauna in this highly isolated island ecosystem. Ancient Hawaiians called this solitary and elusive bat `Ope`ape`a, or half-leaf, as its wings resembled the half-leaf remaining on a taro stalk after the top half has been removed for cooking (Pukui and Elbert 1986). The Hawaiian hoary bat is one of three subspecies including *Lasiurus cinereus cinereus* of North America and the South American subspecies, *Lasiurus cinereus villosissimus* (Tomich 1974). Although the Hawaiian hoary bat was listed as an endangered species in 1970, and is presently protected by both federal and state laws (U.S. Fish and Wildlife Service 1970), current information regarding natural history and population status of this bat is scarce, resulting in incomplete and sometimes conflicting reports.

Population estimates for the Hawaiian hoary bat have ranged from hundreds (Altonn 1960) to thousands of individuals (Tomich 1974), but these numbers are based on anecdotal and incomplete data. To date, researchers know very little about population numbers and yearly trends for this species (Fullard 1989; Tuttle 1995). Menard (2001) suggests that abundance and distribution patterns may fluctuate according to season and altitude on the island of Hawai`i. Based on visual and audio observations of flying bats, she noted that during the "non-breeding period" from September to March, Hawaiian hoary bats were marginally more common in the eastern highlands of the Hakalau Forest National Wildlife Refuge (three sites ranging from 1604 m to 1890 m elevation, mean July minimum temperatures 8-10°C), than during the "breeding period" from April to August when bats seem to shift into the lowlands of the island (20 sites ranging from 0 to 1,280 m, mean July minimum temperatures 11-20°C). This occurrence of bats in the lowlands from April to August agrees in part with Tomich (1986a), who noted that during those months Hawaiian hoary bats "were regularly seen" at sites from 300 m to 790 m elevation along the Hamakua Coast on the northern section of Hawai`i Island. However, in apparent contrast to the high occurrence of bats that Menard reported from April to August at coastal sites, Tomich (1986a) considered bats as "scarce" at the coast from May through August. Contradicting observations by both Menard and Tomich, Jacobs (1994) found no evidence of altitudinal or regional migration at foraging sites distributed over a broad altitudinal and geographical range on the island of Hawai`i during a study from February to August in 1992.

Sightings of the Hawaiian hoary bat have occurred from sea level to as high as 4,115 m at the summit crater of Mauna Loa Volcano (Tomich 1974). They have been observed flying and/or resting in a wide variety of both native and non-native vegetation types and landscapes (Tomich 1986b; Kepler and Scott 1990; Jacobs 1994; Reynolds et al. 1998; Menard 2001). *L. cinereus semotus* is typically a solitary foliage roosting bat, but some bats will use man-made structures and rock crevices (Tomich 1974). Furthermore, it is unclear to what extent this subspecies uses lava tubes. On 2 August 1977, Fujioka and Gon (1988) observed 16 bats flying around an overhanging ledge of a collapsed lava tube on the island of Hawai`i, and others have found bat remains in lava tubes on Hawai`i and Maui (Tomich 1974).

The Hawaiian hoary bat's ability to adapt to various habitats combined with limited and inconsistent information has made associating it with particular habitat types very difficult. As a result, it is not possible to designate critical roosting and foraging habitat for this subspecies, so even the most basic management strategies are difficult to implement (U.S. Fish and Wildlife Service 1998). The U.S. Fish and Wildlife Service (1998) developed a Recovery Plan for the Hawaiian Hoary Bat, which aims to downlist this subspecies. However, this can only happen after populations on the island of Hawai`i are stable or increasing for at least five consecutive years. Threats to this species remain unclear, but habitat loss, pesticide use, predation (Tuttle 1995), and roost disturbance are issues to consider when developing management and monitoring strategies.

The three main objectives of the Hawaiian hoary bat inventory were to: 1) Determine presence/no detection of bats in national parks and adjacent areas on the islands of Hawai`i, Maui, and Moloka`i, 2) assess distribution and relative activity levels of bats in these national parks, and 3) suggest general associations between bats and selected habitats and elevations. Results of the Hawaiian hoary bat inventory will be used as a tool in development of a long-term monitoring protocol for these bats in the Pacific Island Network (PACN).

METHODS

Study Area

Historically found on all the main Hawaiian Islands, Hawaiian hoary bat populations appear to be highest on Hawai`i and Kaua`i (Tomich 1974). We conducted intensive bat surveys in four national parks on the island of Hawai`i: Hawai`i Volcanoes National Park (HAVO), Pu`uhonua o Hōnaunau National Historical Park (PUHO), Kaloko-Honokōhau National Historical Park (KAHO), and Pu`ukoholā Heiau National Historic Site (PUHE). Although we did not systematically survey the Ala Kahakai National Historic Trail (ALKA), parts of the trail pass through all four parks on Hawai`i. In addition, we surveyed Kalaupapa National Historical Park (KALA) on Moloka`i and Haleakalā National Park (HALE) on Maui. In and around all parks, surveys included areas of variable vegetation cover. Maps showing points and transects surveyed and vegetation types are shown in the results section. However, vegetation classifications vary slightly between parks, or were not identified such as in PUHE and KALA, since GIS layers are currently not standardized.

Hawai`i Volcanoes National Park

Established on the island of Hawai`i in 1916, HAVO is approximately 134,679 ha in size, extending from sea level to 4,169 m elevation. It encompasses the summits and rift zones of two of the world's most active volcanoes, Kilauea and Mauna Loa, and includes the newly acquired Kahuku addition on the Southwest Rift Zone of Mauna Loa, as well as nearly 13,354 ha of rain forest in the `Ōla`a Tract. The park, largely surrounded by natural areas and lightly populated rural areas, has only minimal development within its boundaries.

Since 1983, Kilauea has been continuously erupting, while Mauna Loa's last eruption occurred in 1984. In addition to geological processes and volcanic activity, scientists and visitors alike recognize HAVO for its unique flora and fauna. Seven ecological zones, including seacoast, lowland forest, mid-elevation woodland, rain forest, upland forest, subalpine, and alpine, are found within the park and harbor distinct plant and animal communities. Other natural features contributing to the park's bio-diversity are cave ecosystems, anchialine pools, and wetlands.

Pu`uhonua o Hōnaunau National Historical Park

PUHO, on the island of Hawai`i's western side, is located makai, or seaward, of Hōnaunau and is 74 ha in size. This park is located at the shoreline of Mauna Loa Volcano and is mostly coastal in nature. Brackish fishponds and wetlands, anchialine pools, springs, a cliff, and coastal strand communities are found in the park. Towards the southern border there is a stretch of coastal dry forest of mostly alien species, including opiuma (*Pithecellobium dulce*), koa haole (*Leucaena leucocephal*), and kiawe (*Prosopis pallida*).

Kaloko-Honokōhau National Historical Park

Located on the shoreline of the Hualālai Volcano on western Hawai`i Island, KAHO is 469 ha in size with almost half of this area in marine waters. Natural resources include coral reefs, beaches and rocky shores, anchialine pools, two man-made brackish fishponds with associated wetlands, former dryland forest, and bare lava fields.

Pu`ukoholā Heiau National Historic Site

PUHE, another coastal national park located on the western side of Hawai`i Island, sits on a bluff overlooking Kawaihae Harbor in South Kohala. Because it lies on the leeward side of the island and tends to receive little precipitation, the park and surrounding land are arid with little vegetation. In the rainy season, two streams flow in the park and converge to reach the ocean only when flow is high. On its north side, PUHE borders a small boat harbor with commercial shipping facilities, while the southern edge of the park abuts Samuel M. Spencer County Park. A county road runs just inside the northeastern boundary line and the western coastal boundary borders a shallow harbor partially enclosed by a stone breakwater. Of the park's nearly 35 ha, 25 ha are federally controlled and 10 ha remain non-federal. A stream, which originates outside the park, feeds a small wetland area, providing habitat for *Palemon debilis* (glass shrimp) and many freshwater plants.

Kalaupapa National Historical Park

Located on the island of Moloka`i, KALA is roughly 4,370 ha in size. The Kalaupapa Peninsula, adjacent cliffs and valleys, and submerged lands and waters out to 400 m from shore make up the park. Sea cliffs, narrow valleys, a volcanic crater, rain forest, lavatubes, caves, and offshore islands and waters are all present within park boundaries. Kauhakō Crater, formed by a remnant volcanic rim rising over 137 m, contains a crater lake more than 244 m deep, while Waikolu Valley contains the only perennial stream in the park. Through cooperative agreements, the National Park Service manages almost all of this land.

Hawaiian people inhabited the Kalaupapa peninsula and valleys for hundreds of years, before the settlement at Kalawao was established in 1866. Many surviving Hansen's disease patients still live in the community of Kalaupapa, on the leeward side of the peninsula.

Haleakalā National Park

Originally designated as part of Hawai`i National Park in 1916, HALE was established as a separate entity in 1961. The park is located on east Maui and rises from sea level, at Ka`āpahu and `Ohe`o, westward to the summit of Mount Haleakalā (3,055 m). HALE encompasses 12,215 ha, of which 10,003 ha are designated as wilderness. It is exposed to both moist windward tradewinds, where slopes may receive 305 cm of annual rainfall, and drier leeward air. The Summit District of the drier west side of the park is comprised of Haleakalā Crater, portions of its outer slopes, and the upper ends of the Kaupō and Koolau gaps. The wetter Kīpahulu District includes Kīpahulu, Kuiki and Kaumakani planezes, upper Hāna rain forest, `Ohe`o/Puhilele coastal areas, and the new Ka`āpahu addition. HALE contains a number of natural ecosystems, including alpine cinder desert, sub-alpine shrublands, sub-alpine grasslands, montane bogs and lakes, rain forests, mesic forest, and coastal strand. The park also contains the `Ohe`o stream ecosystem, which is a natural riparian habitat with its entire length inside national park boundaries.

Selection of Survey Points and Transects

Non-random fixed survey points and transect locations were determined based on the size of each park, accessibility and safety, and potential suitability of habitat for roosting and/or foraging bats (i.e., forested areas along roads and trails, areas of high insect density, and/or locations of previous bat observations). Survey areas were limited to the parks and immediate vicinities.

Because of its large size, limited accessibility, and extremes in elevation, we established 24 survey points in HAVO, with 12 “high elevation” points (between 1,005 m and 2,011 m) and 12 “low elevation” points (sea level to 1,005 m). Points were spaced a straight-line distance of 2,500 m apart. We distributed points along Hilina Pali Road, Chain of Craters Road, Crater Rim Drive, Highway 11, and Mauna Loa Strip Road (Figure 1).

For the smaller parks (PUHE, KAHO, PUHO), surveys were conducted at points within park boundaries and in immediately surrounding areas. We spaced survey points in these parks 800 m apart. We surveyed PUHO from points located along the 1871 Trail, the Great Wall shoreline, and on Highway 160. We conducted surveys in KAHO at points placed along trails and boundary lines, at the adjacent Honokōhau Harbor, the Aimakapa and Kaloko Fishponds, and near the visitors’ center. A central point was located within park boundaries at PUHE, the smallest of the west Hawai`i parks, on an overlook between the heiau and the newly constructed visitors’ center, and additional points were distributed throughout the surrounding vicinity (Figure 2).

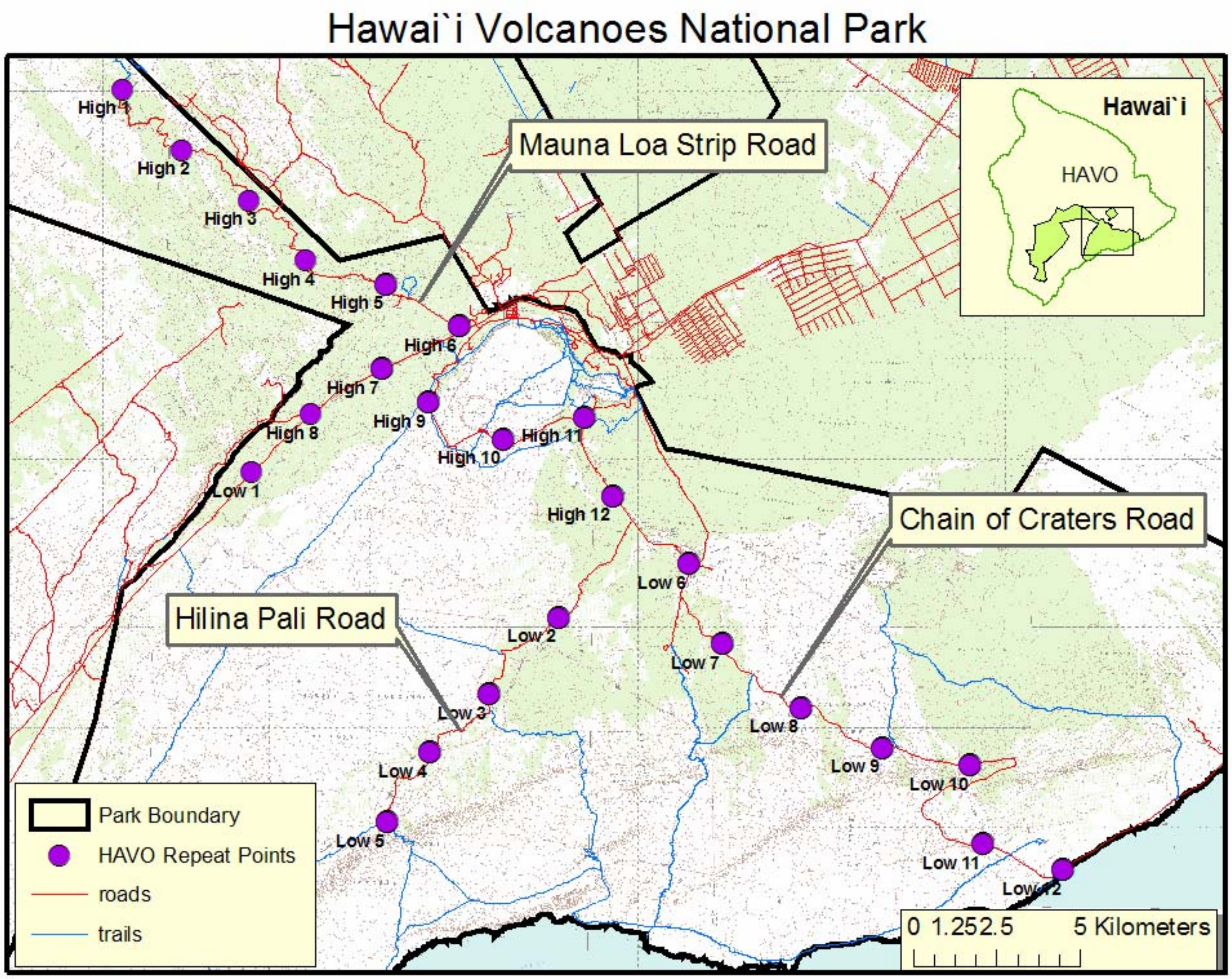

Figure 1. High and low elevation repeat survey points established in Hawai`i Volcanoes National Park on the island of Hawai`i during Hawaiian hoary bat surveys from April to August 2005.

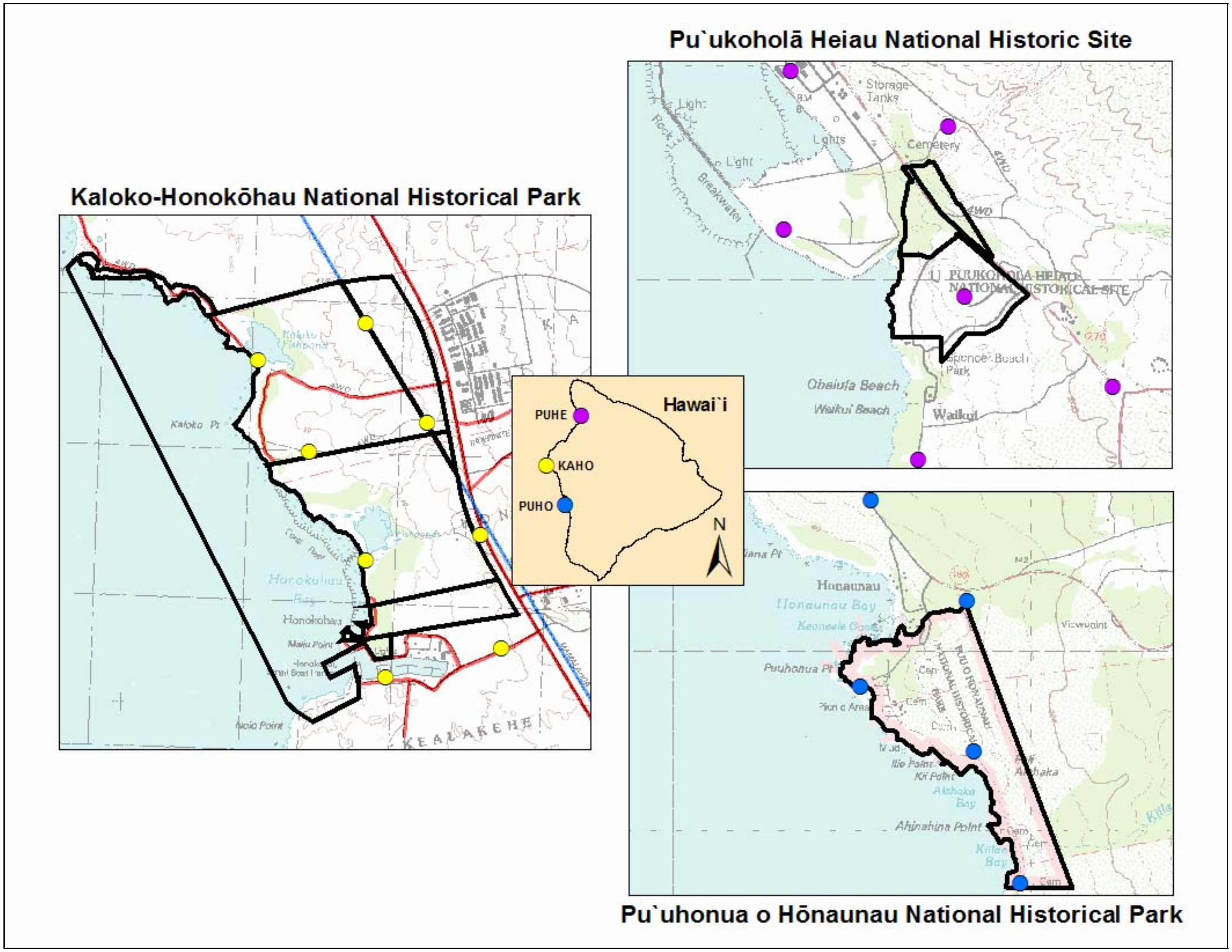

Figure 2. Repeat survey points established in Pu`uhonua o Hōnaunau National Historical Park (PUHO), Kaloko-Honokōhau National Historical Park (KAHO), and Pu`ukoholā Heiau National Historic Site (PUHE) on the west side of Hawai`i Island during Hawaiian hoary bat surveys from April to August 2005.

Surveys of KALA (Figure 11) and HALE (Figure 12) were limited due to time and budget constraints; however, we surveyed sections of major trails and roads in late-May/early-June 2005. We selected survey areas in these parks based upon accessibility and safety, previous bat sightings by park staff, and habitat characteristics (i.e., areas near freshwater, possible foraging and/or roosting habitat, and shelter from the strong year-round winds in KALA).

Survey Methods

We conducted acoustic surveys for *L. cinereus semotus* in these national parks between April and July of 2005. Visual observations were important to locate flying bats during sunset and early-morning surveys, but we focused primarily on using acoustic detection equipment. We used ultrasonic detectors to determine the presence or absence of echolocating bats at fixed points and along transects and to listen for feeding activity.

Handheld Mini-III ultrasonic bat detectors (Ultra Sound Advice, U.K.) were used to convert bat echolocation calls into clicks that are audible to human ears. One limitation of using bat detectors is the difficulty in distinguishing multiple species of bats; however, because only one species of bat is present in the Hawaiian Islands, this was not a constraint. Following methods used by Jacobs (1994), the Mini-III detectors were set to 30 kHz, which is the peak foraging echolocation frequency used by the Hawaiian hoary bat (Belwood and Fullard 1984). Surveys began one half-hour before sunset and continued for two hours post sunset, ensuring that periods of greatest evening bat activity were monitored (Menard 2001). Occasionally, we did surveys for one hour before sunrise, to account for possible morning activity at selected sites (Reynolds et al. 1998).

Acoustic detections were categorized as ‘passes’ (single or multiple low repetition clicks) or ‘buzzes’ (rapidly repeating clicks which occur more frequently as the bat approaches a prey item), which indicate feeding (Fullard 1989; Jacobs 1993; Cabrera 1996). We did not attempt to capture the number of passes or feeding buzzes/unit time, we simply recorded presence/absence of a bat and presence/absence of a feeding buzz. In order to make general suggestions regarding habitat associations (i.e., areas where hoary bats were observed foraging), we relied on the detection of feeding buzzes. Because it is not possible to differentiate between several passes by one bat or single passes by several bats (Fenton 1970; British Columbia Resources Inventory Committee 1998; Johnston 2002), direct population density estimates are not feasible (Thomas and West 1989; British Columbia Resources Inventory Committee 1998; Johnston 2002). In addition to audio detections, we recorded visual observations and attempted to count individuals only when sufficient light permitted.

Locations of bats detected visually or aurally, as well as transects and points visited, were recorded with a Garmin 76C GPS unit using the Universal Transverse Mercator, North American Datum 1983, zone 5Q.

Repeat Surveys

Repeat surveys were conducted at all fixed points in four national parks (HAVO, KAHO, PUHE, and PUHO) on the island of Hawai`i. This allowed for continued monitoring of specific sites within each park over several months. We visited each point on at least six separate occasions over a 14-week period from mid-April to late-July, with at least one week between visits. We surveyed each point both acoustically and visually, depending on available sunlight, for 15 minutes. Random visit order was used to reduce temporal effects on detection probabilities (Jacobs 1994; Reynolds et al. 1998). Bat presence/no detection was recorded along with notes regarding feeding buzzes, habitat, number of bats identified, mode of detection (visual or aural), weather variables, and time of detection. Presence/no detection data collected in the Hawai`i Island parks during repeat surveys were analyzed using program PRESENCE (Hines and MacKenzie 2004). Because few species are so conspicuous that they are always detected when present at a site, the probability that a site is actually occupied may be underestimated (i.e., naïve estimate). Therefore, through analysis of detection histories from repeatedly surveyed sites, the probability of detecting the species is determined, which then allows researchers to generate an unbiased estimate of the proportion of sites occupied (Psi) (MacKenzie et al. 2002). We used a single season output model for data analysis with program PRESENCE, which assumes that all parameters are constant across sites and no changes are occurring to the state of occupancy to any sites during the sampling season.

Non-Repeat Surveys
In order to provide more thorough survey coverage of important selected areas and to supplement park distribution records, we conducted non-repeat surveys in all parks between February and July. These surveys included one-time visits to selected points and transects that were traveled by foot or by a slowly moving vehicle (<24 km/h). Transects were generally selected along trails and roads that could be safely walked at night. Random stops (5-20 minutes duration) were made in open areas along these transects and in areas believed to be potentially suitable for roosting/foraging bats. We report information collected through non-repeat surveys as incidental sightings.

Data from this inventory for all six national were entered into NPSpecies - the National Park Service Biodiversity Database available at
https://science1.nature.nps.gov/npspecies/web/main/start

RESULTS

We detected various levels of Hawaiian hoary bat activity in or around all national parks on the islands of Hawai`i, Maui, and Moloka`i, during summer surveys in 2005. Based on repeat visits to 24 HAVO survey points, we estimate that 33% (Psi = 0.3343, naïve estimate = 0.25, detection probability = 0.2089) of our study sites were occupied by bats. Because the parks on the west side of Hawai`i Island are small in size, we pooled presence/no detection data from all 19 repeat points distributed across PUHO, PUHE, and KAHO for analysis and found that bats occupied 44% (Psi = 0.4362, naïve estimate = 0.368421, detection probability = 0.2668) of these points (Table 1). Because we did not have repeat survey points established in KALA and HALE, we did not calculate the proportion of sites occupied by hoary bats in these parks.

Table 1. *Proportion of sites occupied (Psi) by Hawaiian hoary bats during inventories in national parks on the island of Hawai`i. Surveys were done between April and July 2005. Standard Errors for Psi and detection probabilities are shown in ( ).*

Park	No. Sites	No. Sampling Occasions	Naïve Estimate	Psi	Detection Probability	Variance-Covariance Matrix	
						Psi	p
HAVO	24	6	0.25	0.3343 (0.137309)	0.2089 (0.084191)	0.0189 -0.0059	-0.0059 0.0071
PUHO KAHO PUHE	19	6	0.368421	0.4362 (0.141766)	0.2668 (0.082477)	0.0201 -0.0045	-0.0045 0.0068

In general, we detected a peak in bat activity approximately 40-60 minutes after sunset in HAVO, as well as in PUHO and KAHO (Figure 3), during surveys from April to July 2005. When comparing monthly bouts of bat activity in these parks, we found that Hawaiian hoary bats emerged later (40-60 minutes post-sunset) from April to June, but began to appear much earlier in the evening (20-25 minutes post-sunset) during July (Figure 4). We heard feeding buzzes in native and mixed (native/non-native) vegetation types in HAVO, but predominately non-native areas in PUHO and mixed or other areas of KAHO (Figure 5). Although bats used both native and mixed vegetation in HAVO, all of these feeding buzzes occurred in forested habitat. This was similar for HALE and KALA, where we detected all feeding buzzes along forested edges. We detected bats foraging over bare lava and coastal shrub at PUHO, but most often we observed them foraging over the open ocean. At KAHO we detected bats foraging over areas of open fresh/brackish ponds, as well as shrubland (Figure 6).

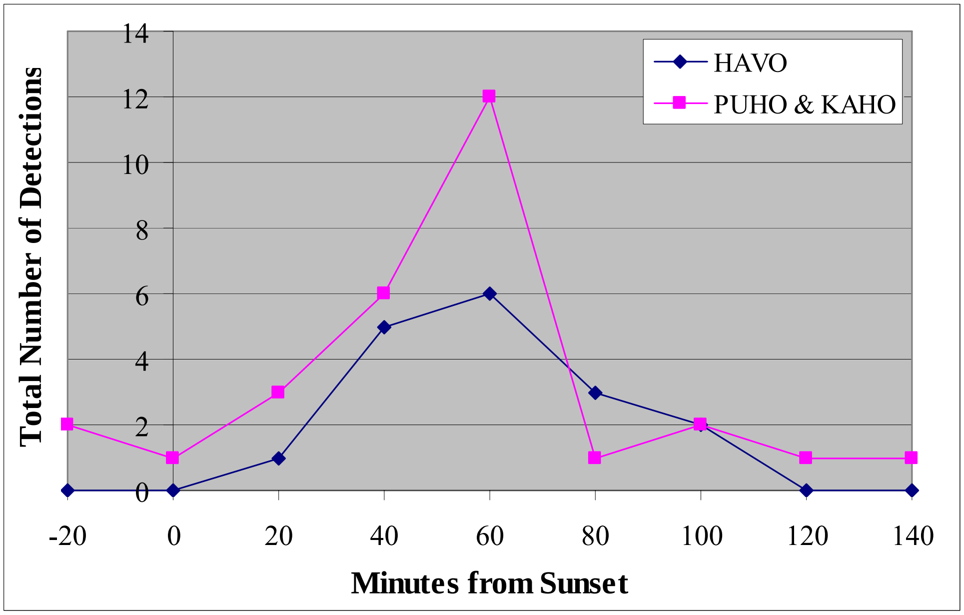

Figure 3. Hawaiian hoary bat evening activity patterns during surveys from April to July 2005 in national parks on the island of Hawai`i. Total number of bat detections is given in 20-minute intervals relative to sunset, where zero equals sunset.

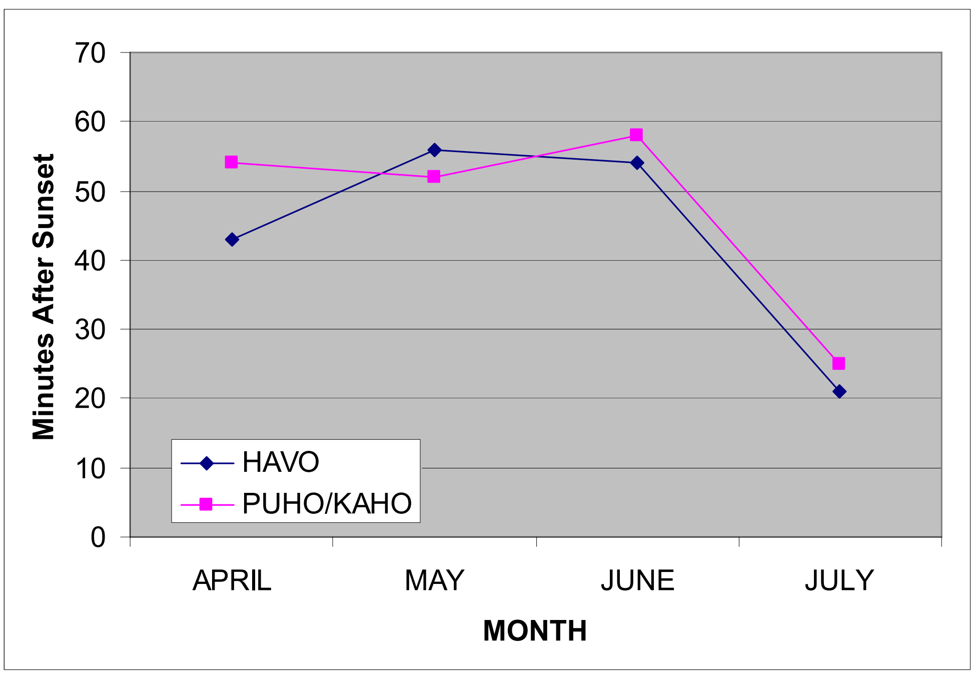

Figure 4. Hawaiian hoary bat monthly activity patterns during surveys from April to July 2005 in national parks on the island of Hawai`i. The average time of bat detections is represented as minutes after sunset, where zero equals sunset.

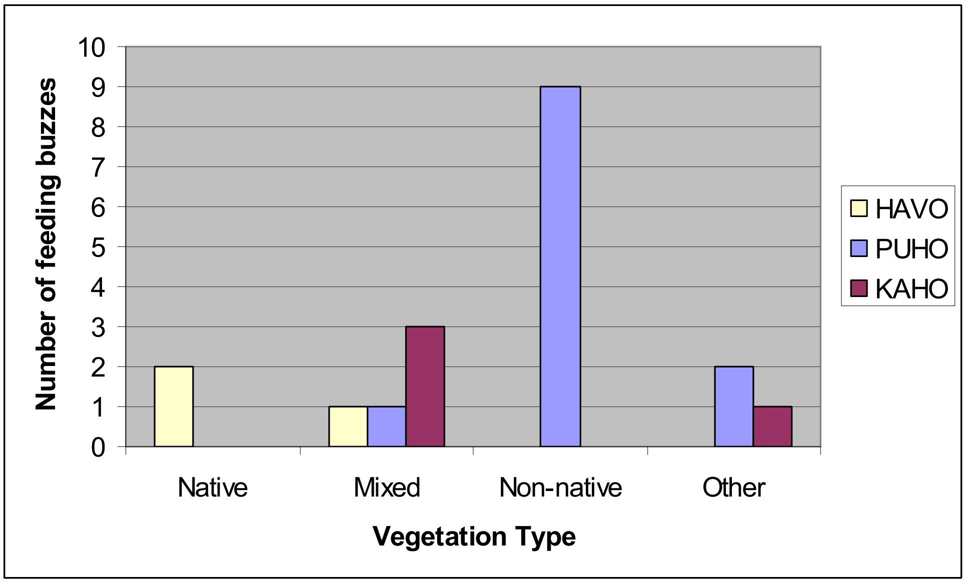

Figure 5. Hawaiian hoary bat feeding buzzes detected during surveys from April to July 2005 in native, mixed, non-native, and other (i.e., fresh/brackish water, open ocean, and bare lava) vegetation types in national parks on the island of Hawai`i.

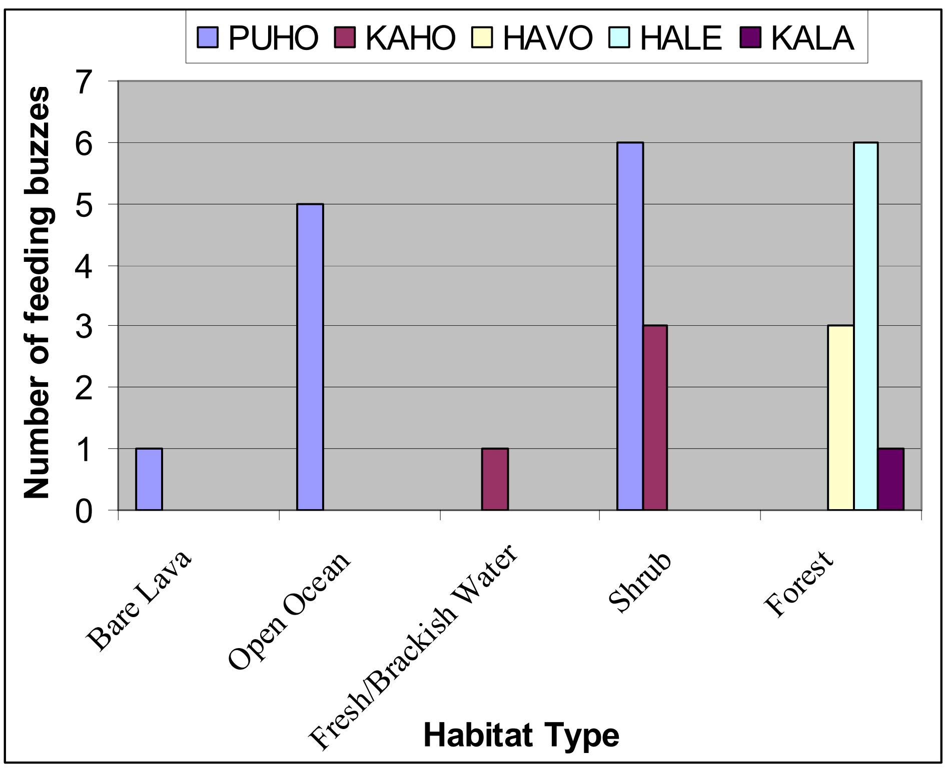

Figure 6. All Hawaiian hoary bat feeding buzzes detected during surveys from April to July 2005 in various habitats in national parks on the islands of Hawai`i, Maui, and Moloka`i.

Hawai`i Volcanoes National Park

In HAVO, we recorded 17 bat detections during 10 of 41 survey nights. Of these, nine detections occurred at high elevation repeat survey sites along Mauna Loa Strip Road, while two detections occurred along Highway 11 (points High-8 and Low-1), and the remaining six were incidental sightings also recorded at high elevation points (Figure 7). Point High-1 was surrounded by dominant ohia and mamane trees, while High-2 was dominated by koa with moderate stature native trees sub-dominating. At High-3, koa and mamane dominated, whereas koa and ohia were dominant at High-4. All incidental sightings occurred in high elevation areas (above 1,005 m) with koa and koa/mamane/manele (*Sapindus saponaria*) dominant trees. Bats detected at points Low-1 and High-8 occurred in ohia dominant areas. Detections began as early as 1912 h and were heard as late as 2023 h, but we detected most echolocation calls before 2000 h. We heard only three feeding buzzes while surveying HAVO. These occurred at Waldron's Ledge overlook, where an edge is created by ohia (*Metrosideros polymorpha*) and faya (*Myrica faya*) trees growing along the side of Kilauea Caldera, and at points High-1 and High-3 between mid-May and early-June.

Other areas surveyed in and near HAVO included Devastation Trail, Escape Road, `Āinahou Ranch, Halapē Shelter area, Keahou Shelter area, `Āpua Point, and Wright Road where it leads to the `Ōla`a Tract. We surveyed each of these areas once between March and July, with the exception of `Āinahou Ranch, which we surveyed on two separate occasions. We did not detect bats in any of these areas. However, Kathleen Misajon (pers. comm.) reportedly disturbed a Hawaiian hoary bat roosting under the eaves of the `Āinahou Ranch house on 18 April 2005 at approximately 1100 h.

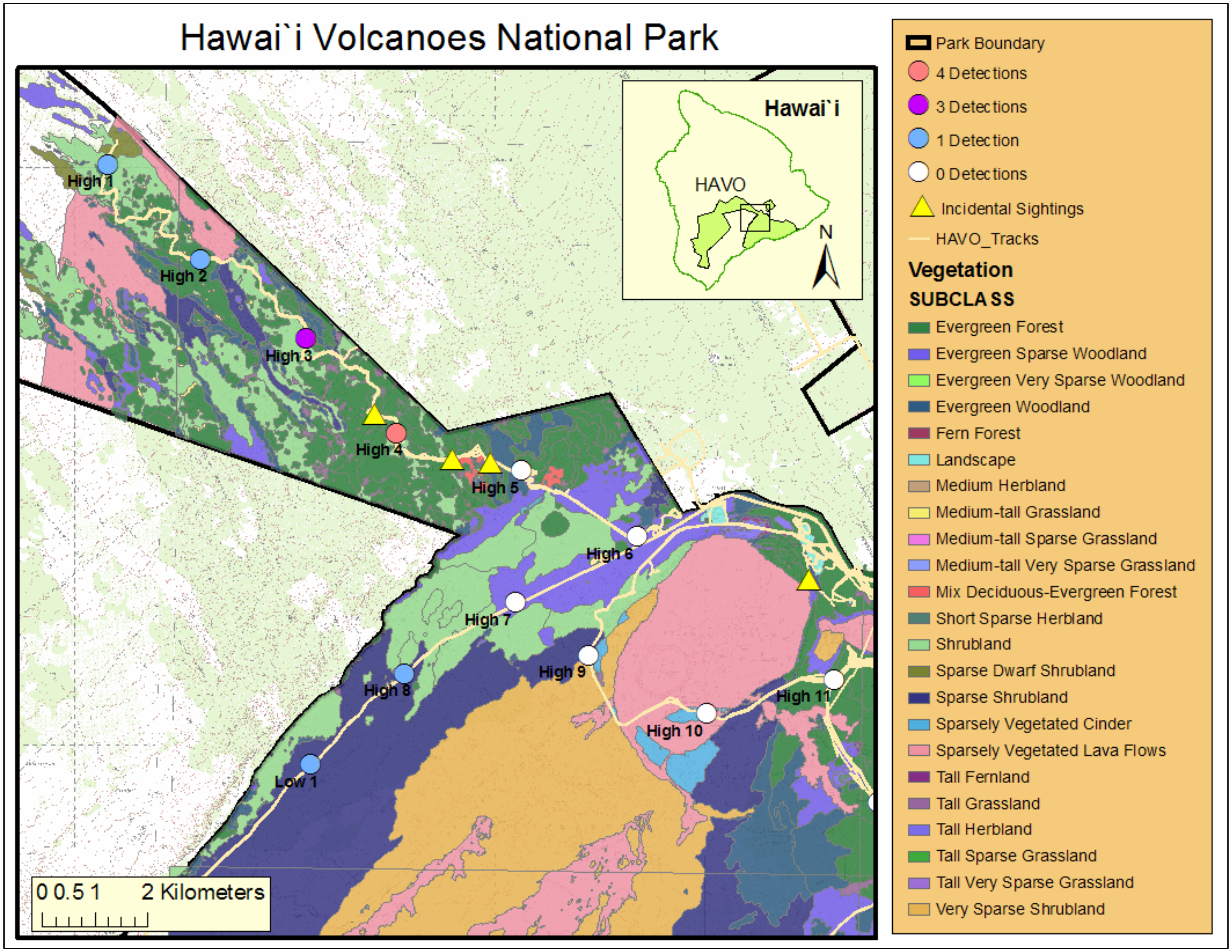

Figure 7. Map of Hawai`i Volcanoes National Park on the island of Hawai`i. Repeat survey points (●) visited and incidental bat detections (▲) observed during Hawaiian hoary bat surveys from April to July 2005 are shown, as well as tracks surveyed throughout the park.

Pu`uhonua o Hōnaunau National Historical Park

We observed bat activity during 10 of 11 survey nights in this park. On 22 April 2005, we recorded nine bats foraging between 10-40 m offshore from point PUHO-4. This was the greatest number of individual bat sightings from any park during the survey. We recorded most bat detections in areas of non-native vegetation. These detections were heard most often between points PUHO-4 and PUHO-5 along ecotones where koa haole and tree legumes create edges with the ocean. We detected numerous feeding buzzes in many areas along the 1871 Trail, but they occurred most often along the southern portion of the trail and at points PUHO-4 and PUHO-5. Of 22 total detections, we recorded 11 from repeat survey points, while additional incidental bat detections were recorded in the main visitor parking lot, along the 1871 Trail, over barren lava, and among coconut trees near the visitors' center (Figure 8). We detected bat activity at each repeat point at least once during the survey.

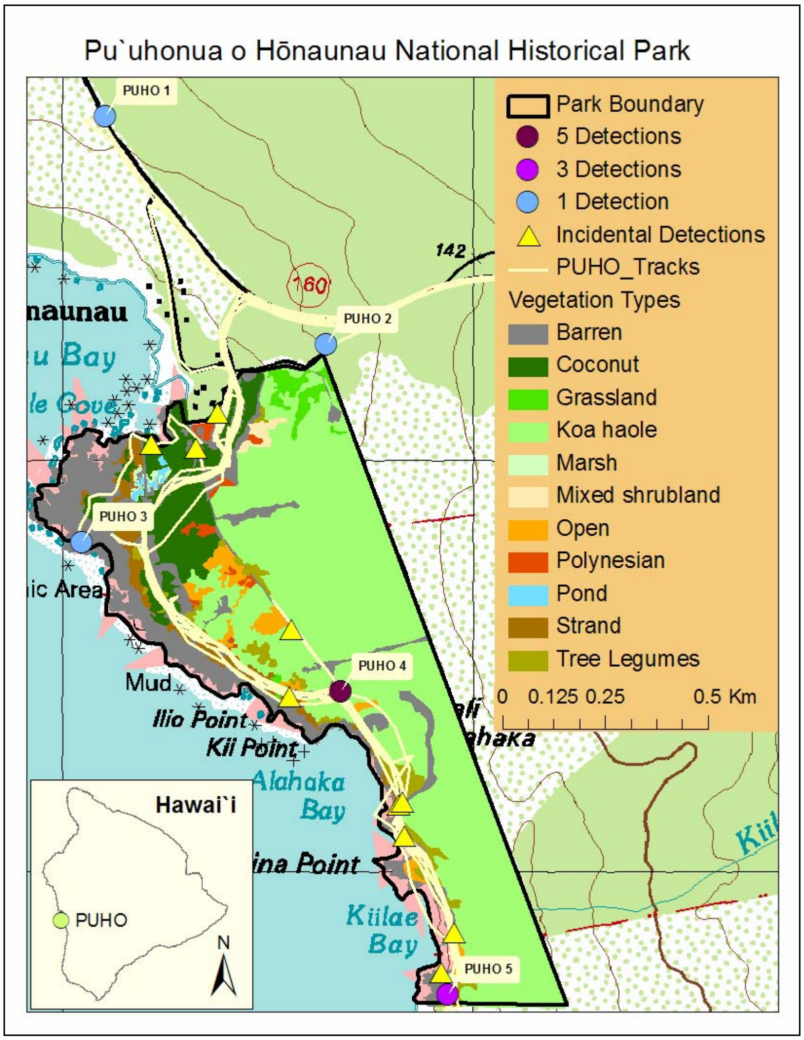

Figure 8. Map of Pu`uhonua o Hōnaunau National Historical Park on the island of Hawai`i. Repeat survey points (●) visited and locations of incidental bat detections (▲) observed during Hawaiian hoary bat surveys from April to July 2005 are shown, as well as tracks surveyed throughout the park.

Kaloko-Honokōhau National Historical Park

Between March and July, we detected bats on only four of 15 survey nights in KAHO. At least two bats were foraging above the Kaloko fishpond (KAHO-1) on 21 April 2005. Additionally, a detection at repeat survey point KAHO-7 occurred on 24 May 2005 near the Kaloko Harbor, when a single bat pass was observed. We also detected bat activity near the KAHO canoe house (inland/strand forest) and along Highway 19 near the park boundary (Figure 9). With the exception of one late-May detection, all bat activity in this park occurred in April.

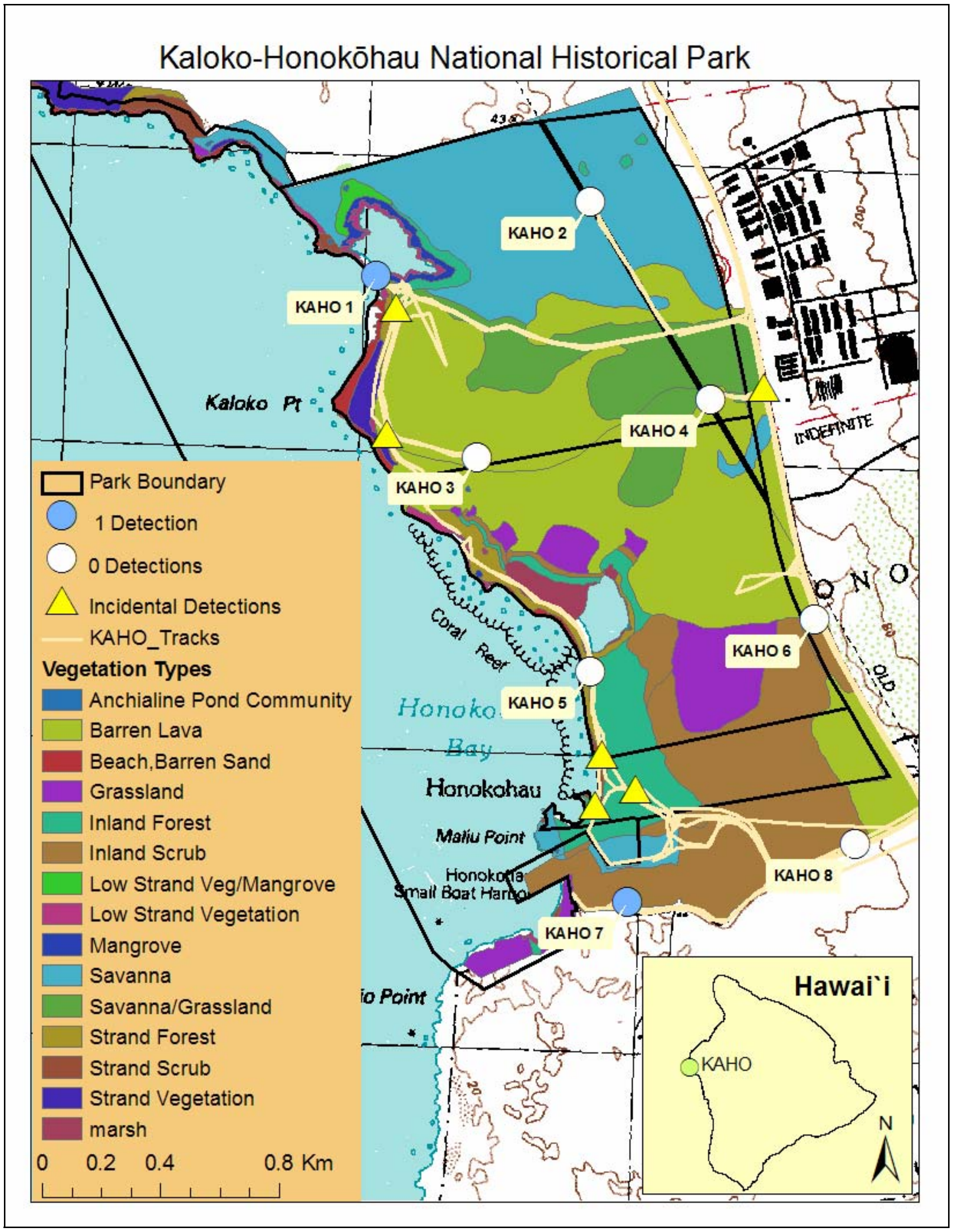

Figure 9. Map of Kaloko-Honokōhau National Historical Park on the island of Hawai`i. Repeat survey points (●) visited and locations of incidental bat detections (▲) observed during Hawaiian hoary bat surveys from April to July 2005 are shown, as well as tracks surveyed throughout the park.

Pu`ukoholā Heiau National Historic Site

We surveyed PUHE on 12 separate nights between March and July. Although we detected a brief feeding buzz on 26 May 2005 in the parking lot of the neighboring Samuel M. Spencer County Park, we did not detect bats here in additional surveys. Furthermore, no bats were detected at any of the repeat survey points established in PUHE, nor were any incidental detections made anywhere within park boundaries (Figure 10). The map for this park does not show vegetation classifications, as GIS layers are not currently available. Reports from an adjacent landowner (near point PUHE-2) suggest that bats were more common in the area approximately 5 years ago (Stew Dela Cruz, pers. comm.), but that recent sightings have been very rare. However, members of park staff indicate that hoary bats are active at dawn near the park maintenance shed during winter months (Bernard Gomes, pers. comm.). We did not find any bats active in this area during two early morning surveys in July.

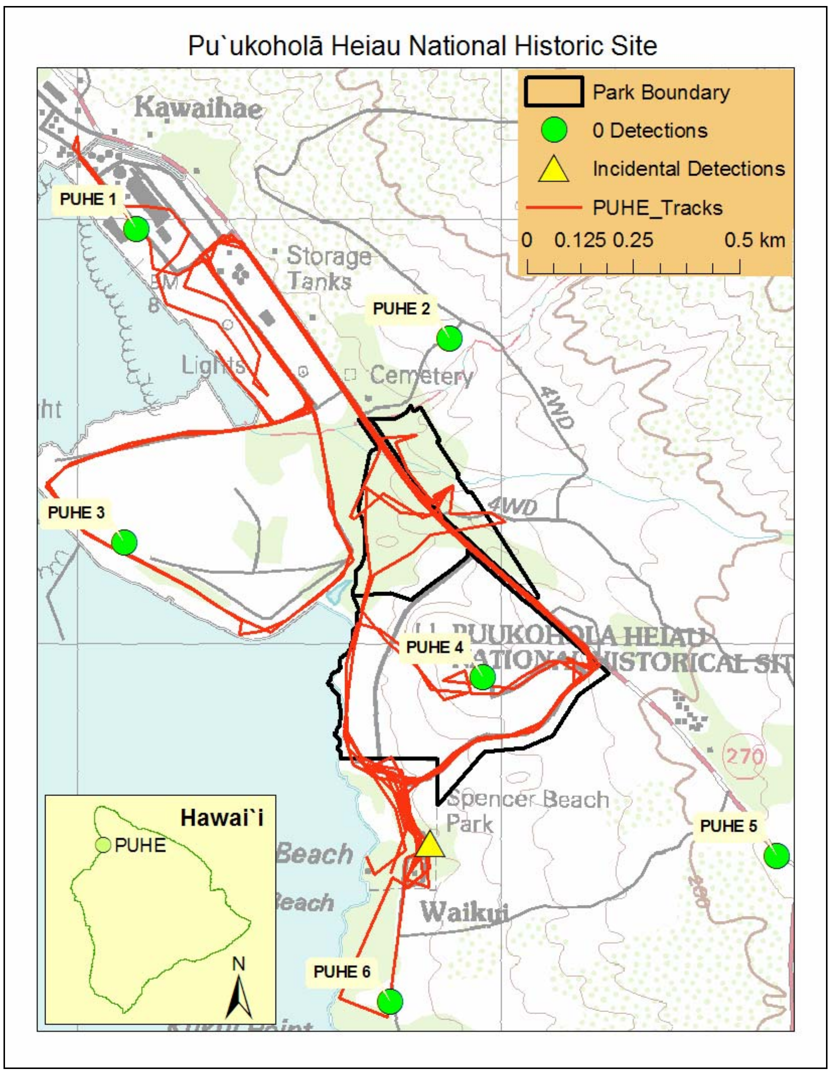

Figure 10. Map of Pu`ukoholā Heiau National Historic Site on the island of Hawai`i. Repeat survey points (●) visited and locations of incidental bat detections (▲) observed during Hawaiian hoary bat surveys from April to July 2005 are shown, as well as tracks surveyed throughout the park.

Kalaupapa National Historical Park

During our time visit to this park in June 2005, we detected bats on only one night within park boundaries. Additionally, we heard a second detection, including a feeding buzz, just outside of KALA at the Pālā`au State Park picnic area (Figure 11). Both detections occurred in forested areas on 9 June 2005, approximately one hour prior to sunrise. These detections were about twenty minutes apart and within roughly 200 m of each other. The map for this park does not show vegetation classifications, as GIS layers are not currently available.

We did not detect any bats on the peninsula itself. Heavy winds year round would seem to discourage bat activity there. A brief survey of Waihānau Valley resulted in no bat observations, and we were unable to explore other valleys due to time constraints. Aside from seasonal sources of freshwater in these valleys resulting from periods of heavy rains, the only source of freshwater on the peninsula is the lake at the bottom of Kauhakō Crater. We surveyed the crater area for a single night (1830-2000 h) from two points; one mid-way down the trail to the crater lake and one approximately 25 m above the lake. Both of these areas seemed suitable for bat activity, due to their proximity to fresh water, shelter from winds, and intact canopy cover; however, we did not detect any bats at these locations.

Little information was available regarding previous sightings or evidence of bats within this park, but previous reports by park staff indicate that bats are active at dusk and dawn during the spring season at the summit of the Kalaupapa Trail. We also interviewed several long-term residents, but they had no knowledge of bats on the Kalaupapa peninsula.

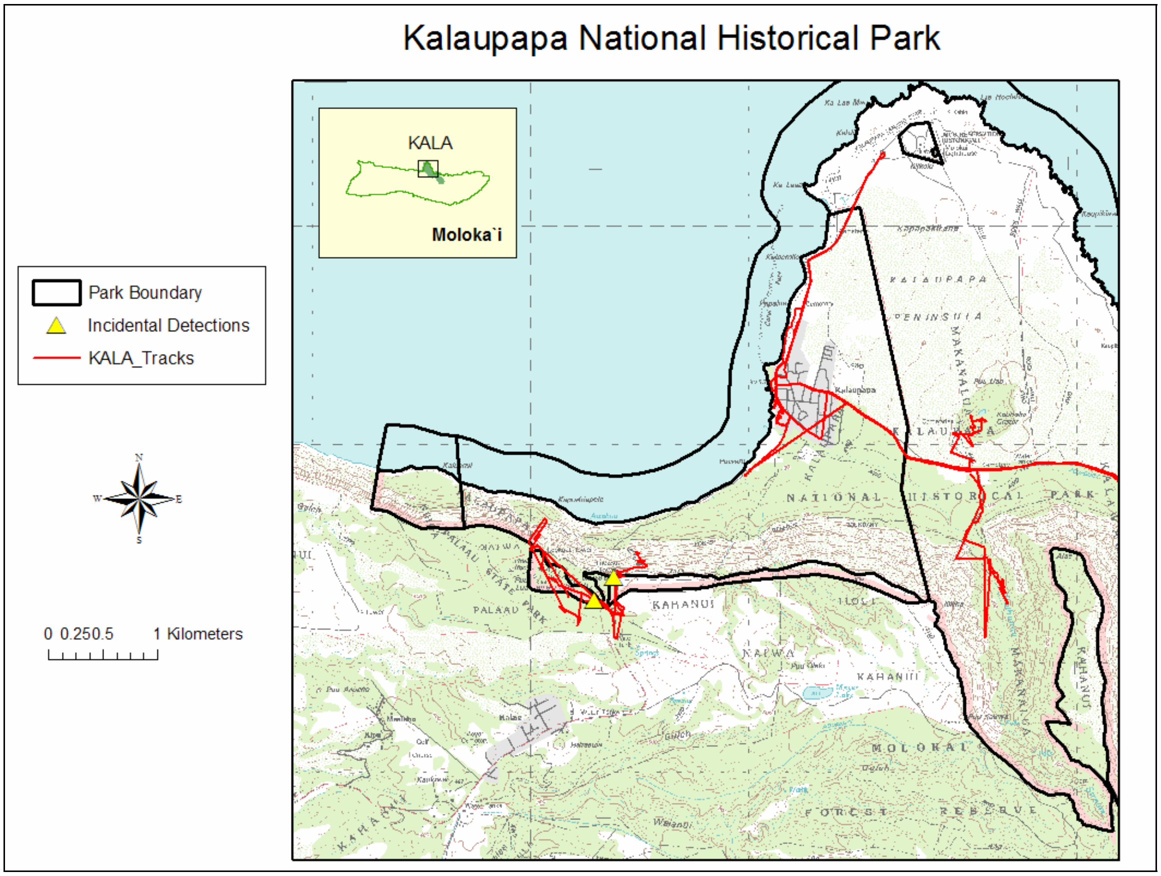

Figure 11. Map of Kalaupapa National Historical Park on the island of Moloka`i. Locations of incidental bat detections (▲) observed during Hawaiian hoary bat surveys in June 2005 are shown, as well as tracks surveyed throughout the park.

Haleakalā National Park

Time constraints restricted surveys to a small area of this park over a six-night period. We did nighttime surveys of the Hosmer's Grove (2,100 m) area, which is predominantly shrubland, on 31 May and 2 June 2005, as well as a morning survey on 3 June 2005. During these surveys, we observed bat activity on only 31 May (Figure 12), when we detected five feeding buzzes along the southern edge of Hosmer's Grove.

From 3 June to 5 June 2005, we conducted dusk and dawn surveys in the Kīpahulu maintenance yard and bunkhouse area, but we did not detect any bats. We extended this survey to the open area of the adjacent campground, areas of semi-forested pastureland north of the bunkhouse and maintenance yard, and along the Pipiwai Trail. A single detection was made along the Pīpīwai Trail in a mixed forest/grassland area down-trail from Kapaha Farm at approximately 1945 h on 4 June 2005.

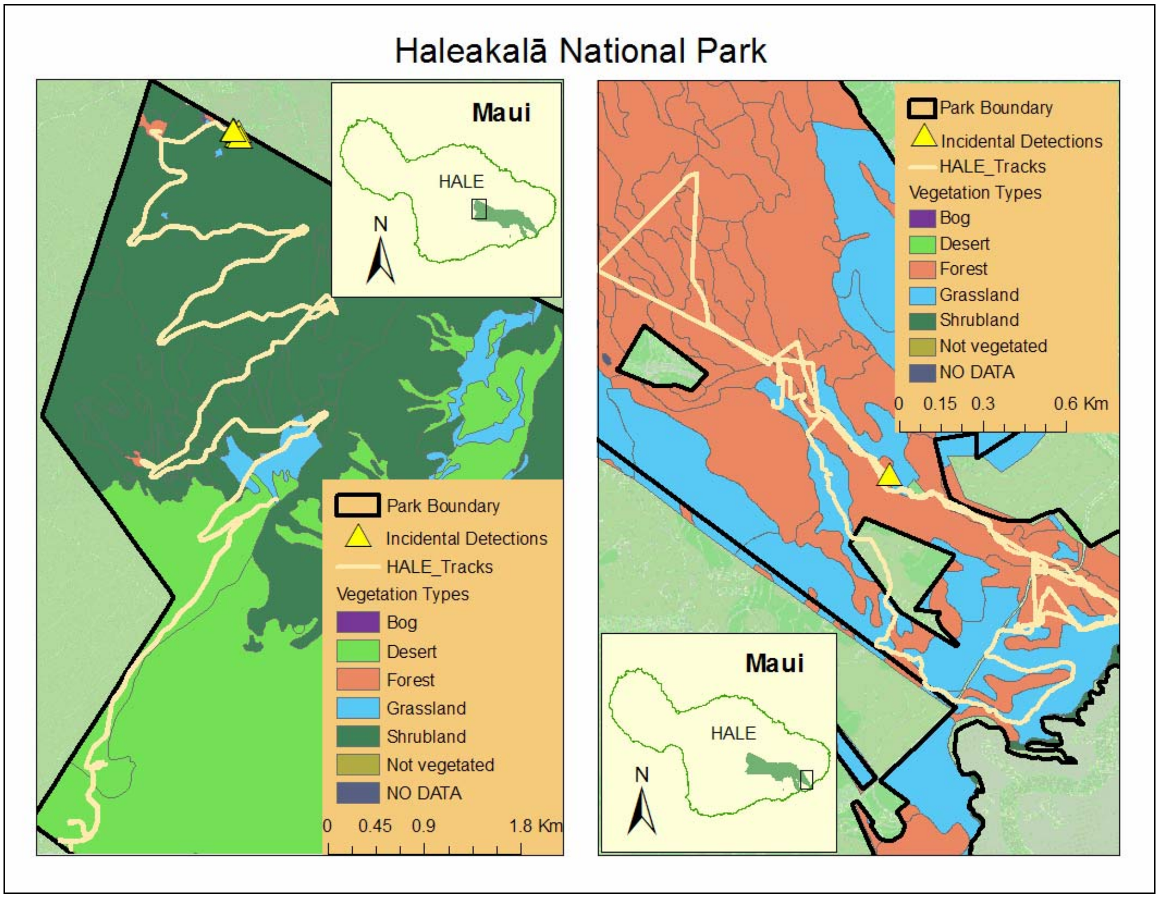

Figure 12. Map of Haleakalā National Park on the island of Maui. Locations of incidental bat detections (▲) observed during Hawaiian hoary bat surveys in late May and early June 2005 are shown, as well as tracks surveyed in the park.

Discussion

The main objective of this survey was to determine presence of *L. cinereus semotus* within six national parks of the Hawaiian Islands. With the exception of PUHE, we observed Hawaiian hoary bats demonstrating varying degrees of activity within boundaries of all Hawaiian national parks that we surveyed. Due to the difficulty in capturing these bats and locating roosting sites, we relied on bat echolocation activity to determine areas occupied by Hawaiian hoary bats. Oliveira (1998) suggests that bats detected at sunset are likely to be roosting nearby, and since most echolocation calls were heard early in the evening (within an hour after sunset), it may be possible that important roosting habitat exists in close proximity to areas where Hawaiian hoary bats were detected.

In regards to seasonality and timing of detections during this study, we recognized earlier mean emergence times for bats in all Hawai`i Island national parks beginning in July. This is consistent with a study by Kepler and Scott (1990) who recorded Hawaiian hoary bats flying earlier in the evening between August and December. They attribute this earlier emergence to fledging juveniles that are just beginning to forage on their own.

These young bats are most likely less efficient at finding and capturing food and therefore need more time to feed and meet nightly energy requirements. Likewise, Jacobs (1994) also suggested that an observed increase in Hawaiian hoary bat activity at some sites on the island of Hawai`i during September and October 1992 might be a result of fledging young of the year.

Another goal of this survey was to investigate possible habitat associations that exist between Hawaiian hoary bats and native, non-native, and mixed vegetation types, as well as forest edges, ponds, open ocean, and barren areas. Because we selected our study sites primarily in areas of accessible roads or trails, we detected bats most often along forest edges and openings. This supports finding by Reynolds et al. (1998), who observed 57% of Hawaiian hoary bat detections in the Puna District of Hawai`i Island along forest edges and open areas of roads they surveyed, as well as reports by Kepler and Scott (1990), who suggested that bats occur most often along mesic forest edges, rather than in the forests themselves. Because Lasiurines typically forage along wooded edges (Barbour and Davis 1969), ecotones created by roads and ocean edges may provide important foraging habitat for this subspecies in Hawai`i. However, our results, as well as Reynolds et al. (1998), are likely biased due to site selection, as bats may simply be more visible along edges.

In previous Hawaiian hoary bat surveys, Kepler and Scott (1990) recorded only 19% of bat observations from native vegetation, while roughly 64% were recorded in areas of exotic vegetation. This differed from a study by Jacobs (1994) associating these bats most often with areas of native vegetation. During our summer surveys in 2005, almost all bat detections in HAVO occurred along Mauna Loa Strip Road in areas of native forest, especially among koa and ohia. This high occurrence of bats in upland forested areas makes sense, as Lasiurine bats are typically obligate foliage-roosting species that use a variety of trees (Shump and Shump 1982, Kepler and Scott 1990) and forage along wooded edges. These areas may be better suited for roosting and/or foraging (i.e., sufficient canopy cover for roosting and/or forest edges providing successful foraging opportunities), while coastal and lower elevation areas of the park may be unsuitable due to windy and barren conditions with only low shrubby vegetation.

Although we did not detect any bats in PUHE, we observed bats in PUHO and KAHO using a variety of vegetation types including non-native vegetation and areas of open water. Areas upslope from PUHE and KAHO are mostly open and covered by old, barren lava flows and grasses. This may explain a lack in consistency of bat activity in these areas, as bats may have to travel greater distances to find adequate canopy cover for roosting. However, areas near PUHO provide more vegetation coverage to perhaps better meet Hawaiian hoary bat roosting or foraging requirements. The abundance of bats at PUHO, combined with the consistency of sightings and feeding buzzes, seems to indicate important foraging grounds.

It is important to note the difficulties we encountered when attempting to associate these bats with particular habitats. Our small sample size and inconsistencies in vegetation classifications across parks did not permit for meaningful statistical analyses. Thus, it seems that Hawaiian hoary bats may be opportunistic and flexible in selecting foraging habitat, but development of a uniform habitat classification system, more thorough survey coverage of these areas during different seasons, and larger sample sizes are necessary before significant comparisons can be made. Further studies regarding prey availability should also be considered before making conclusions linking Hawaiian hoary bats to certain habitats.

Additional surveys in KALA and HALE will be important to better establish distribution patterns and changes in bat activity in these national parks. Our surveys at the summit area in HALE did not reveal any bat detections. However, previous observations of bat-like activity observed during a seabird radar study (Bob Day, pers. comm.) suggest that they are widely distributed here. Furthermore, HALE Resource Management staff has reported seeing bats near the summit fence, Hosmer Grove, and Kaupō Gap, as well as finding several specimens near the south slope fence of the park between 1986 and 1993 (Cathleen Bailey, pers. comm.), also suggesting that Hawaiian hoary bats are active in the park. Although we heard a few feeding buzzes in forested areas of HALE and KALA, we could not draw meaningful conclusions about these parks, as our findings resulted from very limited surveys. In KALA, areas of particular interest for future surveys include the Kauhakō Crater area, the valleys of Waihānau, Wai`ale`ia, and Waikolu, and the forested areas of Kalawao. These areas provide intact non-native canopy cover and adequate protection from the strong winds. Further detections along the Kalaupapa Trail may also provide more insight about bat activity within park boundaries.

Finally, by providing information on the detectability of *L. cinereus semotus*, we were able to calculate site occupancy estimates for hoary bats in the national parks of Hawai`i. Species are sometimes recorded as absent when they are, in fact, present but not detected for a variety of reasons (MacKenzie et al. 2002), which may include seasonal and temporal activities. Previous Hawaiian hoary bat surveys have not considered detectability, which may have lead to low estimates of site occupancy. In our surveys of the national parks on the island of Hawai`i (HAVO, PUHE, KAHO, PUHO) we used detection/no detection histories of repeated site surveys to estimate species detectability and thus a more accurate estimate of the probability that an area is occupied (Mackenzie et al. 2002; Wintle et al. 2004). In HAVO, our naïve estimate of site occupancy differed from the corrected estimate by only 8%. Similarly, the corrected site occupancy estimate for PUHO/PUHE/KAHO was only 7% greater than the naïve estimate. These numbers may seem slight; however, as more repeat points are established and continuously visited, differences between naïve and corrected site occupancy estimates will likely be more significant.

Further knowledge of bat presence and foraging activity within national park areas will aid in future management and monitoring of this species. Baseline information provided from this inventory will help us to identify and select long-term monitoring sites and methodologies for assessing changes in bat activity. Further surveys of HALE and KALA, as well as areas in the recently acquired Kahuku addition in HAVO, should be completed to add to our knowledge of distribution and activity of Hawaiian hoary bats in the national parks of Hawai`i. In addition, future studies should address temporal and seasonal issues, prey availability, and land use or cover.

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